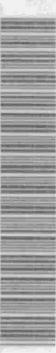


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THUNDER BAY WATER QUALITY REPORT

June 1976



Ontario

Ministry
of the
Environment

The Honourable
George A. Kerr, Q.C.,
Minister

Everett Biggs,
Deputy Minister

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THUNDER BAY
WATER QUALITY REPORT

June 1976

Prepared by:

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Ministry of the Environment

ABSTRACT

This report presents and analyzes findings of the water quality and related subject surveys carried out in the Thunder Bay area since 1970. The main objective of the report is to record the present state of water quality for future reference and also to analyse changes since 1970. Due to the relatively short period of time and some data limitations, not much can be said about the changes of most of the water quality parameters (dissolved oxygen, dissolved solids, conductivity, chlorides, etc.), but some changes are detectable.

The nutrient levels show some of the changes. While the concentrations of the total nitrogen were somewhat lower in 1974 than in 1970, the total phosphorus has increased considerably over the same time. Further increases in the nutrient levels could have an unfavourable impact on the water quality in the bay as well as adjacent Lake Superior waters.

The techniques for determining the amount of asbestos fibres in water are not yet reliable enough to warrant conclusions on the levels of asbestos contamination or changes.

Water movements in the area are predominantly from the north to south with the currents and dispersion rates generally slower in the north part of the bay.

Bottom sediments show some heavy metals contamination especially in the Inner Harbour. Some lake trout samples collected in 1973 and 1974 had mercury contents above the recommended maximum level for human consumption of 0.5 mg/kg.

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THUNDER BAY

INTRODUCTION

Lake Superior is the largest of the Laurentian Great Lakes both in area and water volume. It is agreed (Beeton (1), Schelske and Roth (2) and many others) that the offshore waters of Lake Superior are the most oligotrophic of all of the Great Lakes and that the chemical composition has changed little in the last several decades. The same is not true for some of the nearshore waters where most of the changes in water quality have taken place. In a recent intensive study of the nearshore waters of Lake Superior by the Ministry of the Environment (MOE) (Kinkead and Chatterjee (3)), it was shown that, although the nearshore waters of Lake Superior are for the most part of an excellent quality, some impairment is noticeable and continuing discharges of polluting materials will contribute to water deterioration on a long-term basis.

Thunder Bay is the largest Canadian city on Lake Superior and due to the concentration of population and industry it is a potential contributor to the pollution of Lake Superior. A general view of the Thunder Bay area is shown in Figure 1. The area can be divided into two sections: the Inner Harbour (inside the breakwater) and the Outer Harbour (outside the breakwater). An extensive study of the water quality in the Thunder Bay area was carried out in 1970 and the results published in 1972 (4). At that time, it was concluded that the surface waters in Thunder Bay Inner Harbour and the adjacent section of the Outer Harbour were being contaminated by local industrial and municipal waste water discharges. Recommendations were made to alleviate the pollution pressure in Thunder Bay. Since the publication of the 1970 study, intensive water quality sampling surveys in Thunder Bay were made in 1973 and 1974. This report summarizes the findings and recommendations of the 1970 survey and presents the 1973 and 1974 findings. An attempt is made to establish what changes took place during this time period and to evaluate the changes in water quality of the nearshore and offshore waters.

Water Uses

The waters of the Thunder Bay area must meet a variety of needs some of which are in conflict with each other. The predominant existing uses are domestic and industrial water supply, waste disposal, hydro-electric power generation and commercial shipping. To a lesser extent portions of Thunder Bay are used for boating, angling, and swimming. Each of these uses is discussed below.

Water Supply

a) Municipal - at present the City of Thunder Bay is supplied by two water works: the Thunder Bay North Plant and the Thunder Bay South Plant. The first is capable of pumping 50,000 m³/d (11 MIGD) and

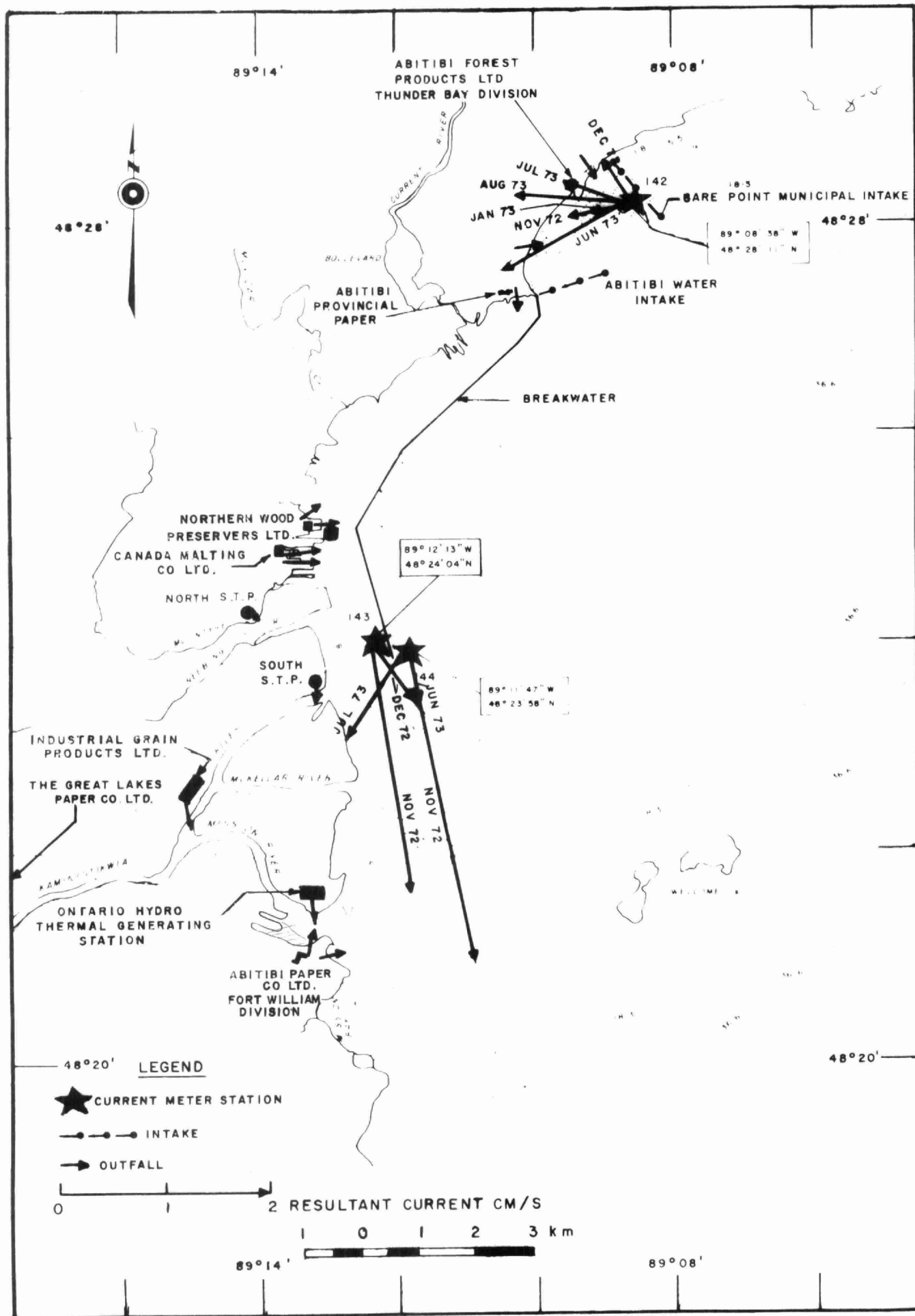


FIGURE 1 : RESULTANT CURRENTS

withdraws water from Thunder Bay through an intake located at Bare Point. The second is rated at 55,000 m³/d (12 MIGD) and withdraws water from Loch Lomond located about 8 km (5 mi) southwest of the mouth of Mission River. Both plants utilize screening and chlorination. The average annual pumpages for the years 1972 to 1974 from the north and south plants were 31,000 m³/d (6.8 MIGD) and 37,300 m³/d (8.2 MIGD), respectively. The treated water distribution systems are being partially integrated to provide more flexible operation and reliability of the supply. In the outlying municipalities wells are the principal source of water supply.

b) Industrial - the largest individual industrial user of water in Thunder Bay is the Ontario Hydro Thermal Generating Station which, when operating, withdraws approximately 540,000 m³/d (118 MIGD) of water from the mouth of Mission River. However, this station only operates intermittently when the load on Ontario Hydro's east-west grid increases. In 1975, the station operated a total of three months.

The pulp and paper industry is another large water user. Of the four major mills in the area the following three - Abitibi Paper Company Ltd. (Fort William Division), Abitibi Forest Products Ltd. (Provincial Paper Division) and Abitibi Forest Products Ltd. (Thunder Bay Division) withdraw 30,900 (6.8), 75,900 (16.7) and 52,700 m³/d (11.6 MIGD), respectively, from the lake for cooling and process purposes (1974 averages). The fourth, owned and operated by The Great Lakes Paper Co. Ltd., is located on and withdraws 151,000 m³/d (33.2 MIGD) of water from the Kaministiquia River.

Several small industries withdraw water from the Bay. Examples are Northern Wood Preservers Ltd. and Canada Malting Co. Ltd. which draw water from the Inner Harbour 24.5 m³/d (5,400 IGPD) and 4500 m³/d (1 MIGD), respectively. Industrial Grain Products Limited withdraws 820 m³/d (0.18 MIGD) of water from the Kaministiquia River. All industries provide treatment for process water prior to use. Overall, the average pumpage for industrial uses other than power generation and paper mills totals about 45,500 m³/d (10 MIGD).

Waste Water Disposal

Some of the watercourses in the Thunder Bay area are used for disposal of treated and untreated wastes from industrial and municipal sources. The major industrial discharges originate from the pulp and paper mills in the area. The City of Thunder Bay is served by two primary sewage treatment plants with one discharging into the McIntyre River and the other into the Kaministiquia River. The City has a combined sewer system with numerous outfalls to the nearest watercourse. These outfalls will be combined by mid-1977 and directed to the sewage treatment plant. Areas outlying Thunder Bay rely on septic tank systems.

Hydro-Electric Power Production

There are two hydro-electric power generating stations on the Kaministikwia River upstream from Thunder Bay with a total capacity of 69,500 kW. Flow regulations for these stations are provided by two dams. An arrangement has been made to discharge at least 17 m³/s (600 cfs) to provide additional dilution water in the lower Kaministikwia River.

Commercial and Recreational Fishing

Commercial fishing, which seriously declined in the period of 1970 to 1972, has made a comeback in Thunder Bay. In 1974 the restriction imposed as a result of high mercury levels on lake trout was lifted. Fish species in order of value of fish commercially caught in Thunder Bay are: whitefish, suckers, lake trout, smelt, menominee, perch, northern pike and burbot. The value of the 1975 catch exceeded \$300,000. In 1974 angling became important to the south-west section of Thunder Bay and in 1975 to the northern section. Anglers experienced more and better fishing than in the past twenty years.

Recreation

The Thunder Bay area has been increasingly developed for recreational uses. On the north shore outside the city there is considerable cottage development and several public beaches. Most of the east shore lies within the boundaries of Sibley Provincial Park. Other small recreational areas are located south of the City of Thunder Bay.

Pleasure boating is developing extensively in the area. Two marinas are located in the Inner Harbour area, while two yacht clubs and a rowing club are located on the Kaministikwia Channel of the Kaministikwia River.

Swimming in the City of Thunder Bay has never been developed extensively. This can be attributed to the cold water of the Bay and poor access to the Bay due mainly to the industrialized waterfront.

Commercial Shipping

Thunder Bay is Canada's western terminus of the St. Lawrence Seaway. Ships are able to navigate up the Kaministikwia River to the Westfort turning basin and operate behind the five mile breakwall that forms Thunder Bay Inner Harbour. Wheat and grain products, iron ore, bulk cargo, paper and wood products, oil, and coal are the major commodities handled at Thunder Bay. In 1974, total cargo tonnage was 18.5 million t.

Dredging Disposal

Sections of the lower Kaministiquia and Mission Rivers are dredged to allow commercial shipping up to Westfort turning basin. In the past approximately 230,000 m³ (300,000 yd³) of sediment, dredged each year from the Kaministiquia River, were disposed of by the Canada Department of Public Works in Thunder Bay near the Welcome Islands. Presently, uncontaminated material (determined by sampling) dredged from the River is being disposed well offshore in the lake at a MOE approved site. Some contaminated material was deposited into a semi-enclosed basin, (Abitibi Paper booming ground) in 1975.

Water Quality

In the 1972 report (4) on Thunder Bay it was concluded that the surface waters in Thunder Bay are being contaminated by local industrial and municipal waste water discharges. The largest source of biological oxygen demand inputs (BOD) were industrial waste water discharges accounting for approximately 95 percent of the BOD inputs into the area. The most seriously affected was the lower Kaministiquia River and the area around its mouth. The impairment of the Thunder Bay Inner Harbour was restricted to the extreme north and south sections, which receive the major waste inputs of the area. The main changes included decreases in dissolved oxygen levels, increases in nutrient levels, and bacterial contamination in excess of accepted criteria for swimming and bathing. The water quality study of Thunder Bay Outer Harbour was restricted to the vicinities of the mill outfalls, sewers, and rivers flowing into the harbour. The main changes included bacterial contamination and aesthetic impairment, particularly in the vicinity of the outfalls. However, at the time of the 1970 study water quality degradation due to the discharges of oxygen-consuming waters and nutrients was not serious in the area.

LIMNOLOGY

To be able to determine the changes in water quality of Lake Superior in the Thunder Bay area, to widen our general knowledge of the lake, and to obtain baseline data for future studies, a variety of physical, chemical, and biological parameters were measured in the area from 1972 to 1974 and are reviewed below.

Physical and Chemical Limnology

Water Movements and Dispersion - Recording current meters were operated at three locations in Thunder Bay (Figure 1) between November 1972 and August 1973, in order to determine the nearshore water dynamics and estimate dispersion characteristics. Monthly records of current meter data were processed by the usual statistical and time series methods (see for example (5)). A summary of the statistics obtained appears in Table 1, and the monthly resultant current vectors are displayed in Figure 1. Results indicate slower and more variable currents at the northern location (142) compared to the southern locations (143 and 144). The southern currents were generally along the shore and toward the south with relatively large persistences, those at the northern

TABLE 1

SUMMARY OF CURRENT METER RESULTS

Period	Nov 72			Dec 72		Jan 73	June 73		Jul 73		Aug 73
Location code	142	143	144	142	143	142	142	144	142	144	142
Resultant speed (cm/s)	0.65	2.54	3.05	0.54	0.81	0.41	1.37	0.59	0.72	1.06	117
Resultant direction coming from 0° as North	79	351	348	146	325	73	64	345	109	35	95
Period of velocity <0.31 cm/s (per cent of recording period)	62	26	30	59	62	79	45	23	33	21	22
Average speed (cm/s)	0.98	3.46	4.06	1.06	0.88	0.47	2.42	4.34	2.64	3.55	4.31
Maximum speed (cm/s)	8.36	22.22	28.01	9.00	10.51	6.30	21.74	27.62	18.04	24.63	27.26
Persistence	0.66	0.74	0.75	0.51	0.92	0.86	0.56	0.14	0.27	0.30	0.27
Percentage of time going in resultant direction	17	45	40	15	29	10	28	21	17	21	19
Dispersion Coefficient m^2/s North		0.140	1.199		0.126		0.290				
For direction East		0.006	0.012		0.002		0.390				
coming from South	LC ^a	0.000	0.000	LC ^a	0.000	LC ^a	0.000	LC ^a	LC ^a	LC ^a	LC ^a
5 h West		0.002	0.062		0.014		0.000				

^a Currents too low and percentage of negligible currents too high to determine any meaningful values of dispersion coefficients.

location were variable and generally toward the shore. In addition, long periods of stagnation (no measurable currents) were observed, particularly in the winter. This reflects the effect of ice cover shielding the water from wind-induced motions. In general, the results indicate that the bay is flushed from the northeast.

Results of the time series analysis indicated the most frequent periodicities to be less than three hours. Periods related to the fundamental Lake Superior oscillations (Rao and Schwab (6)) were absent. Thus, the bay is quite insulated from the lake and the predominant factors controlling the bay currents are the local shore geometry, winds and the variation of water levels in Thunder Bay.

Dispersion coefficients were calculated from the current meter data by Markov chain techniques (Palmer and Izatt (7)). The results, given in Table 1 indicate variability of the values. In the northern areas, similar values result for currents coming from the north and east, while in the southern locations only the dispersion coefficients for the northern currents are relatively significant. Values are lower than those measured in lakes Erie and Ontario (7), thus pollutant dispersion is relatively slower at all locations in Thunder Bay. Residence time in the nearshore region computed on the basis of water chemistry is approximately 22 days (see subsection on exchange of the pollutants between nearshore and offshore waters).

Temperature - The temperature at the sampling sites was measured in situ. Monthly average temperatures, standard deviations, minimum and maximum values are given in Table 2. The data were divided into the surface values (down to 1.5 m from the surface) and bottom values (below 1.5 m from the surface). Only the results for July, August and October are included; there were not enough data for the other months. It is evident that a thermal stratification existed in July and August as the difference between the top and bottom layers temperatures is significant and, also, rapid changes of temperature with depth are noticeable for a few stations where the whole temperature - depth profile was measured. The mean surface layer temperatures in July and August were from 16.4 to 17.5°C with the mean bottom layer values of 11.2 to 14.6°C. In October the whole water column was practically homogenous in temperature with the mean values of 7.6°C in 1973 and 6.4°C in 1974, respectively.

Water Chemistry Surveys - Samples of the water in Thunder Bay were collected from July to October 1973 and May to October in 1974 several times a month. The sampling locations are shown in Figure 2. On some occasions and for some of the stations more than one depth was sampled; however, there was generally no significant difference in the chemistry parameters measured at different depth levels and no attempt was made to distinguish between them. In 1973, several successive surveys were carried out under different wind conditions to remove bias caused by wind. The collected water samples were analyzed for specific conductance, ammonia, total Kjeldahl nitrogen, nitrite, nitrate, total phosphorus, filtered reactive phosphate, chloride, and sulphate. Some of the

TABLE 2
WATER TEMPERATURE, °C^a

Month		July	August	October
1973 Surface Layer	Mean	17.10	17.53	7.65
	Standard Deviation	0.62	1.24	0.90
	Minimum	16.40	10.00	6.80
	Maximum	17.90	20.00	11.60
	Number of Samples	4	86	48
1973 Bottom Layer	Mean	14.45	14.57	7.50
	Standard Deviation	1.23	4.16	0.64
	Minimum	13.20	6.80	6.50
	Maximum	15.90	18.00	8.20
	Number of Samples	4	48	45
1974 Surface Layer	Mean	16.37	-	6.44
	Standard Deviation	1.34	-	0.42
	Minimum	11.20	-	5.80
	Maximum	17.70	-	7.80
	Number of Samples	26	-	27
1974 Bottom Layer	Mean	11.25	-	6.34
	Standard Deviation	2.99	-	0.29
	Minimum	6.40	-	5.20
	Maximum	17.40	-	6.70
	Number of Samples	50	-	84

^aAll data collected down to a depth of 1.5 m below the surface are included in the surface means, all other values are included in the bottom means.

samples were also tested for total and fecal coliform bacteria, enterococci, chlorophyll a, and dissolved oxygen. The summary of data is given in the Appendix, Tables 1 and 2.

Changes in Water Quality Between 1970 and 1974 - To be able to compare the different locations of the harbour area and to calculate stocks of the individual chemicals and, eventually, to calculate the alongshore and offshore components of pollutant exchange, the Thunder Bay Harbour and adjacent area was divided into 24 segments (cells) with four zones (A,B,C,D) parallel to the shore and six zones (1,2,3,4,5,6) perpendicular to the shore (Figure 2). The segmentation was based partly on the bottom morphology and partly on the location of the sampling stations.

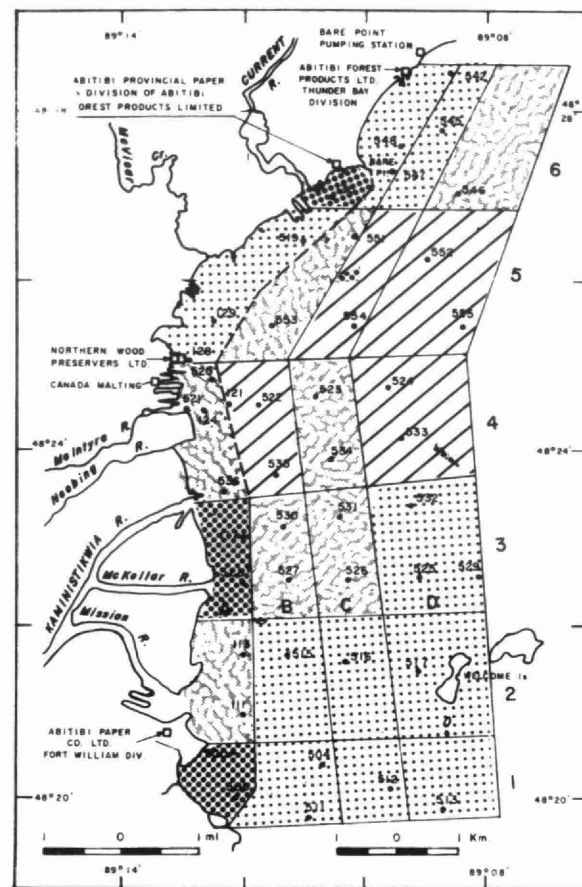
There are from one to four sampling stations in each cell. For the sake of simplicity, it was assumed that the concentration is homogeneous in each grid cell and that the concentration is given by the mean concentration of the sampling station or the mean concentration of all the stations in the cell. The mean depth of each cell was calculated from hydrographic chart data and the surface areas were determined by polar planimeter. This grid system was used to calculate the change of concentration in the individual zones and to show graphically how the concentrations have changed over the years. Some physical characteristics such as volume, depth and surface area for the four zones (A,B,C,D) parallel to the shore are given in Table 3.

The changes in key chemical parameters are discussed below.

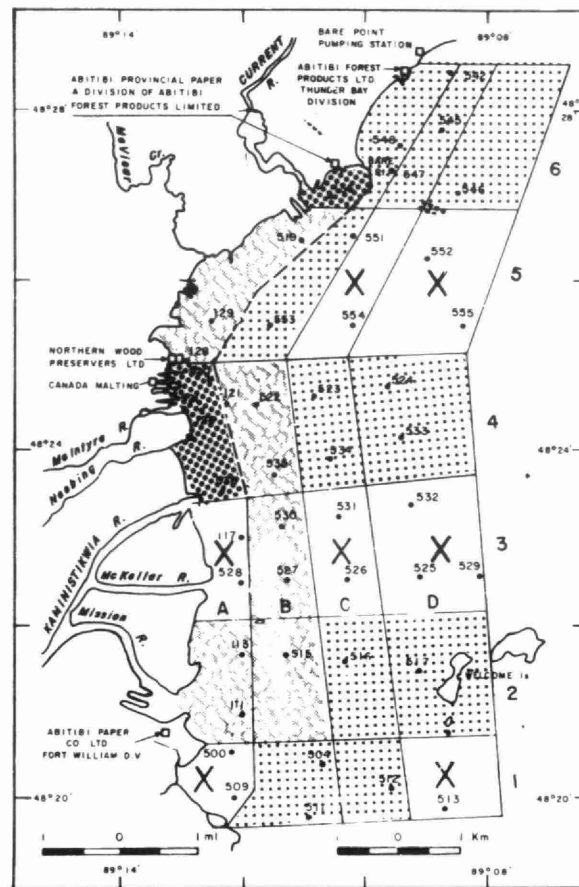
Dissolved Solids - To be able to compare 1970 data for dissolved solids with 1973 and 1974 data, dissolved solids for 1973 and 1974 were estimated from specific conductance data using a conversion factor of 0.65 (9). The changes in the dissolved solids can be seen from Figure 2. There is little change between the years with apparent decrease of the concentrations in the nearshore zones (A and B) in 1974. However, the calculation of the amount of dissolved solids in the whole area (A+B+C+D) has shown that the variation was very small during the compared years (Table 3).

Nutrients

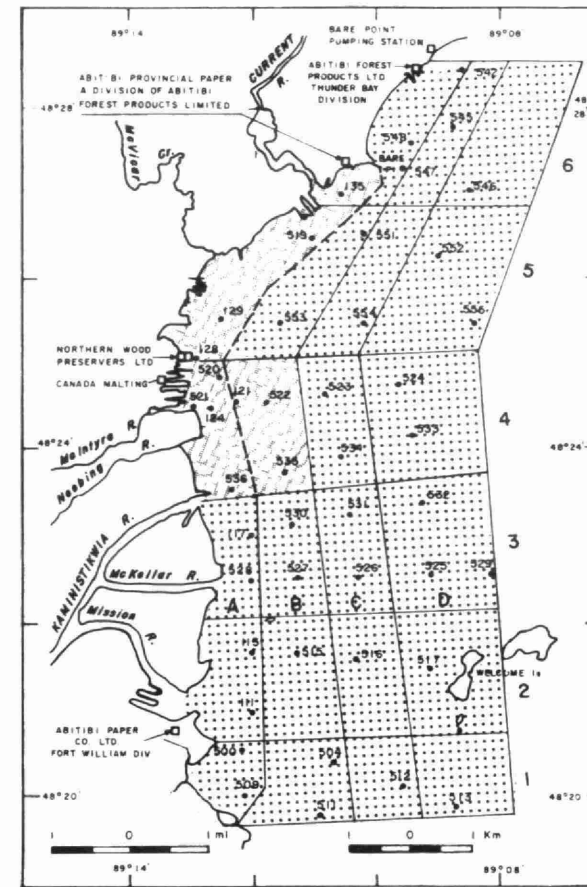
Phosphorus - The total phosphorus concentration has increased considerably since 1970. While the mean value at any station for 1970 was never over 0.053 mg/l (station 521), a mean station value of 0.111 mg/l was reached in 1974 at station 113. The increase is evident from Figure 3; while there was a considerable change between 1970 and 1973 there was further marked increase in 1974. The increase is also obvious from the calculated mass of phosphorus in the nearshore area (stock) given in Table 3. Whereas there were about 10.3 t of phosphorus in the nearshore area in 1970, there were 17.6 t in 1973 and 34.6 t in



1970



1973



1974

LEGEND

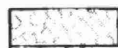
AVERAGE
DISSOLVED SOLIDS
mg/l



< 60.0



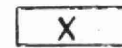
60.1 - 68.0



68.1 - 74.9



> 75.0



NOT AVAILABLE

511

• SAMPLING STATION

FIGURE 2: SAMPLING STATIONS AND CHANGES IN DISSOLVED SOLIDS IN THUNDER BAY 1970 - 1974

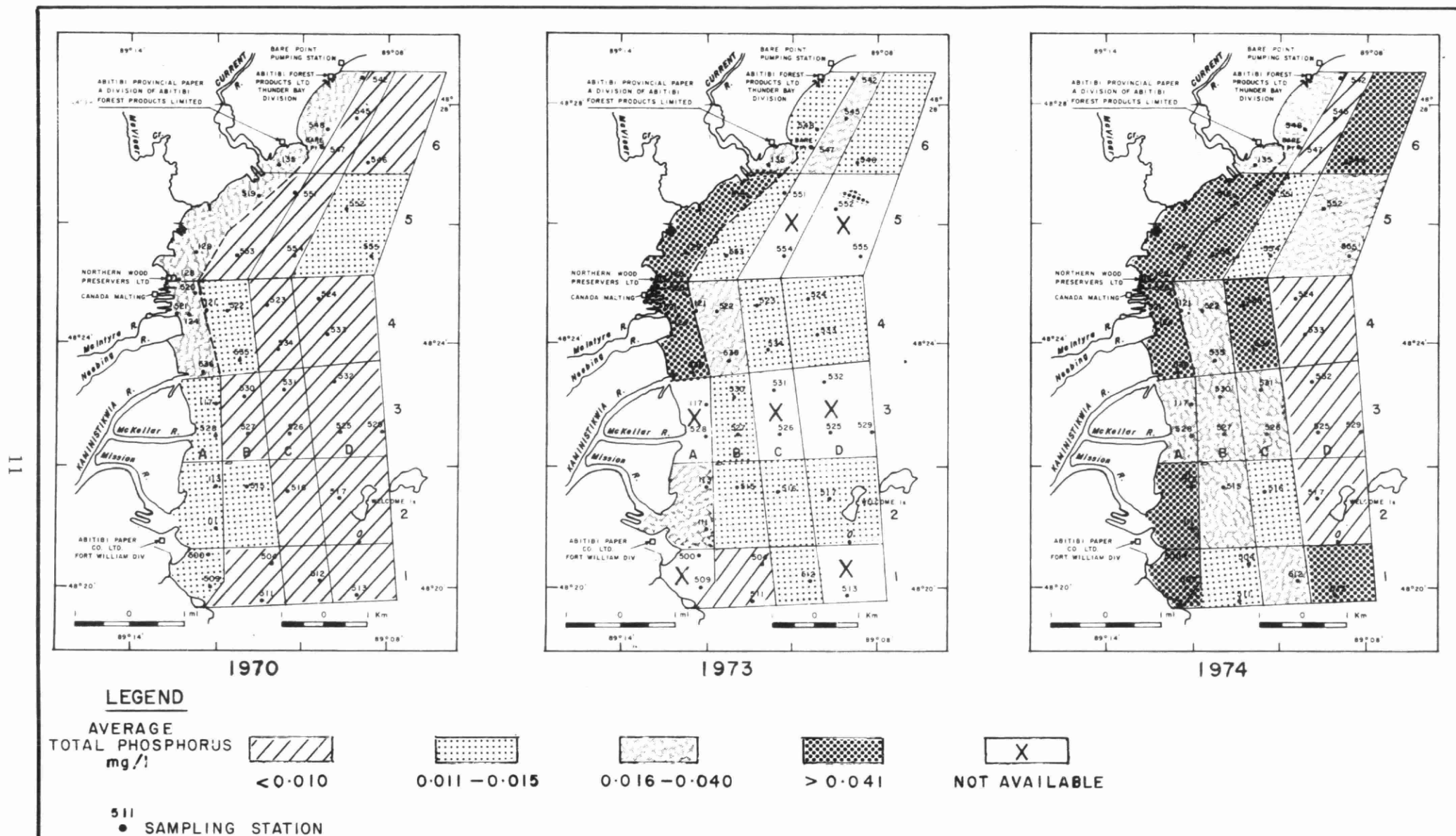


FIGURE 3: CHANGES IN TOTAL PHOSPHORUS IN THUNDER BAY 1970-1974

1974. The range of total phosphorus concentrations of the individual samples varied from 0.002 mg/l in 1970 for several stations in zone D - (Figure 2), to 0.200 mg/l reached near the mouth of the Kaministiquia River in 1974. The concentration changes cannot be explained by changes in the analytical methods - there were no changes of the methods for determination of total phosphorus and nitrogen between 1970 and 1974. The increase in the amount of phosphorus can be regarded as a serious step toward eutrophication of the area. Schelske et al. (10) have suggested that total phosphorus is a limiting factor to phytoplankton growth and production in Lake Superior. However, there is an interrelationship between amounts of phosphorus and nitrogen as phytoplankton growth limiting factors. This is discussed subsequently.

Nitrogen - Nitrogen changes were varied (Figure 4, Table 3). While there was an increase between 1970 and 1973 from 359 t to 430 t of total nitrogen present in the nearshore area there was a decrease to 247 t in 1974. This amount is actually lower than the 1970 value. It is questionable if the decrease in the nitrogen concentration is significant in the overall water quality in Thunder Bay but lower concentrations are certainly desirable. The total nitrogen values vary widely from 0.109 mg/l (reached in 1974 at station 554) to 0.883 mg/l (1973 survey southern part of the bay).

The rates of decrease in concentration of chlorophyll a, dissolved solids, total nitrogen, total phosphorus, and total coliform organisms with distance measured in the offshore direction are presented in Figure 5 for 1970, 1972 and 1974. Total coliforms have the most rapid decrease in all years. The decrease rates of total nitrogen and chlorophyll a for 1973 are similar and different than those for total phosphorus, suggesting that chlorophyll a concentrations may be nitrogen limited. It was suggested by Dillon and Rigler (11) that when the ratio of nitrogen to phosphorus is smaller than 12, chlorophyll a is more likely to be proportional to the nitrogen concentration than to the phosphorus concentration - the nitrogen becomes a limiting factor. The ratios of N/P are given in Table 3. For 1973 (the year with chlorophyll a data) the N/P ratios were mostly well above 12. For 1974, the ratios had dropped in all cases below 12 and it can be speculated that the decrease in the amount of nitrogen in the nearshore area would compensate, to some degree, for the increase of the phosphorus and limit algal production. Integrated biological and chemical surveys are required to test this possibility and future trends.

The data on some key parameters are given for the individual zones in Table 3 which lists mean concentrations and mean calculated stock values. In the 1970 to 1974 period, the total phosphorus mass increases in all zones, especially in zone D, i.e. further offshore. So while the relatively high phosphorus concentrations were present in 1970 mainly in the Inner Harbour, phosphorus levels favourable to increased phytoplankton production had spread much farther offshore in 1974.

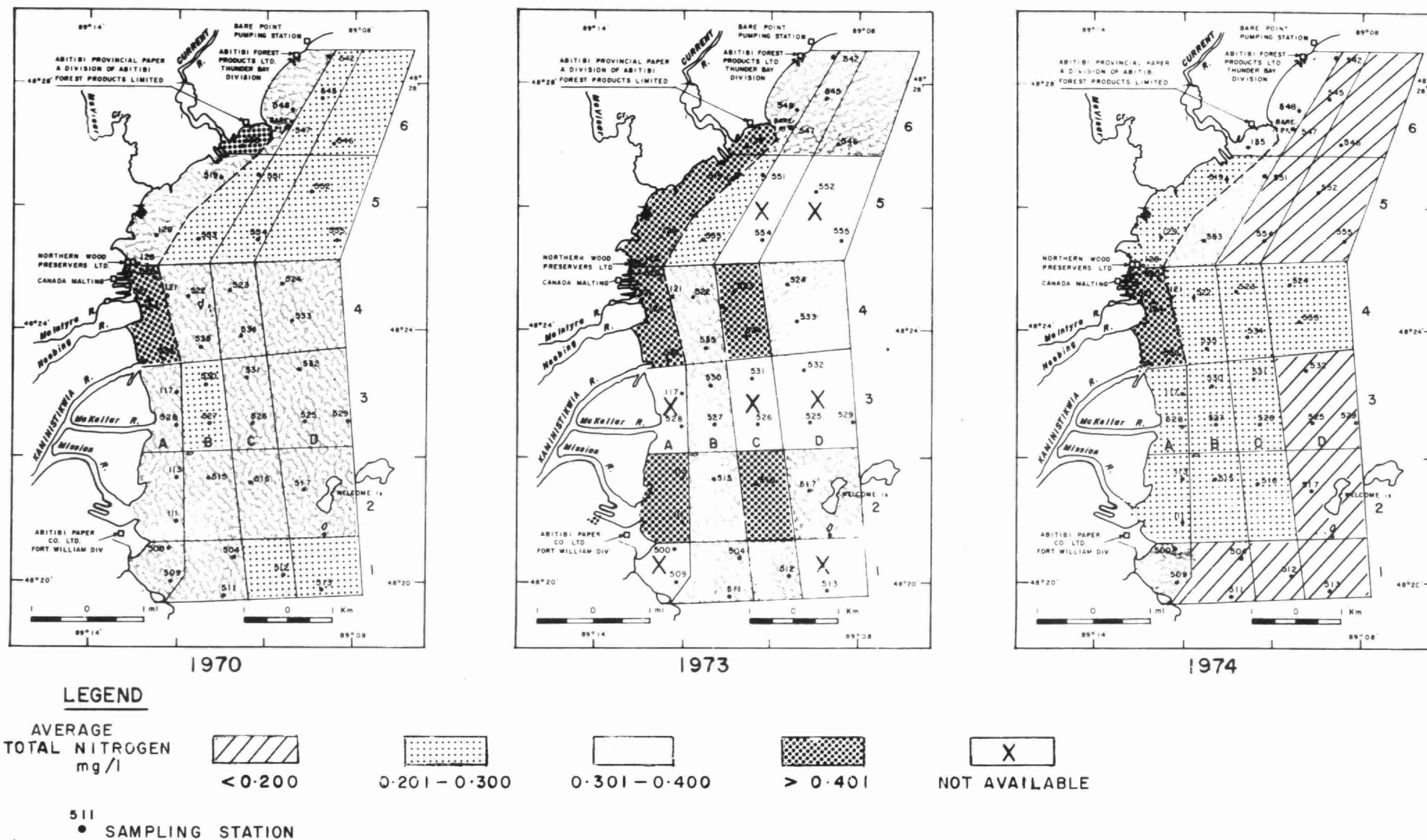


FIGURE 4: CHANGES IN TOTAL NITROGEN IN THUNDER BAY 1970 - 1974

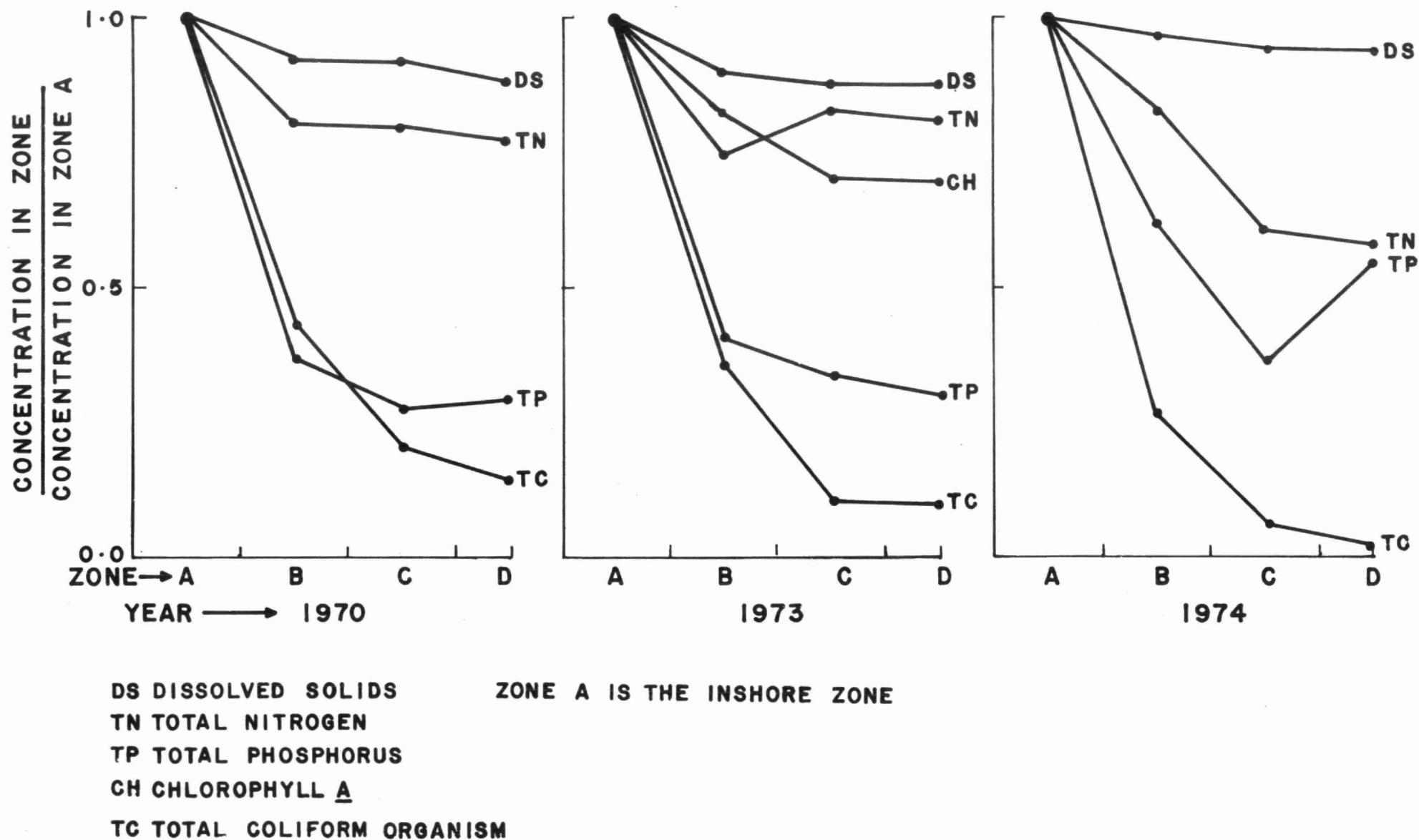


FIGURE 5 : RELATIVE CONCENTRATIONS IN THE DIFFERENT
OFFSHORE ZONES, THUNDER BAY

TABLE 3

THUNDER BAY, NEARSHORE AREA PARAMETERS

ZONE ^a		A			B			C			D			A+B+C+D		
Volume m ³ x10 ⁶		81.9			207.7			287.6			580.0			1157		
Mean Depth m		4.55			9.15			15.8			19.4			13.0		
Surface Area km ²		18.0			22.7			18.2			29.9			88.8		
YEAR		-1970-	-1973-	-1974-	-1970-	-1973-	-1974-	-1970-	-1973-	-1974-	-1970-	-1973-	-1974-	-1970-	-1973-	-1974-
Dissolved	mg/l	70.7	73.8	68.8	65.5	66.6	66.3	65.0	64.7	64.7	62.3	64.5	64.3	64.1	65.6	65.1
Solids	t	5790	6050	5640	13600	12800	13800	18700	18600	18600	36200	37500	37400	74300	76000	75400
Total	mg/l	0.0252	0.0400	0.0548	0.0093	0.0164	0.0338	0.0069	0.0135	0.0200	0.0074	0.0121	0.0298	0.0089	0.0152	0.0299
Phosphorus	t	2.06	3.28	4.48	1.94	3.40	7.02	1.98	3.88	5.87	4.28	7.04	17.32	10.27	17.60	34.59
Total	mg/l	0.387	0.455	0.324	0.313	0.339	0.269	0.309	0.377	0.195	0.298	0.367	0.187	0.310	0.310	0.213
Nitrogen		31.7	37.3	26.5	65.1	70.5	55.9	88.9	108.6	56.2	173.3	213.4	108.6	359	430	247
Ratio																
Total N: Total P		15.4	11.4	5.9	33.6	20.7	8.0	44.8	27.9	9.8	40.3	30.3	6.3	34.8	24.4	7.12
Total Coliforms per 100 ml, Geom. Means		3219	-	1640	1406	-	438	672	46	108	451	40	31	1486	-	450
Chlorophyll <i>a</i> µg/l		-	1.53	-	-	1.31	-	-	1.08	-	-	1.06	-	-	1.24	-
Calculated Number of Flushings per year		-	-	-	-	-	-	-	-	-	-	-	-	4.55	16.8	16.2
Residence Time Days		-	-	-	-	-	-	-	-	-	-	-	-	80.2 ^b	21.7	22.6
Predicted Excess (+) or Deficit (-) in Nearshore Zone per cent of Input																
Phosphorus		-	-	-	-	-	-	-	-	-	-	-	-	64.6	44.6	-24.8
Nitrogen		-	-	-	-	-	-	-	-	-	-	-	-	-59.0	-43.9	47.4

^a Individual zones are shown in Figure 2.

^b Unrealistically low available loading data, resulting value is too high.

Dissolved oxygen data are available for 1970 and 1973. For all 1973 samples and stations the values were relatively high. Only on two occasions (in August 1973 at stations 135 and 521) were values below 5 mg/l (the provincial standard for warm-water biota (12)) reached. Generally, dissolved oxygen levels in the harbour are high and capable of assimilating the waste discharges (13).

Asbestos

An inter-laboratory study of the asbestos fibre levels in Thunder Bay was carried out in 1975 (14). Three laboratories involved in the study were supplied with identical water samples of the Thunder Bay water supply (withdrawn from the bay near Bare Point) and the results are shown in Table 4.

It can be seen that there is a wide spread of approximately two orders of magnitude in the results. Different fibre types were also reported, as well as different numbers and masses of each type. There is no evidence that any laboratory is more correct than the other. The arithmetic means are an indication of the variability of the different analytical methods and of the problem of the determination of the asbestos fibres. The table values illustrate the range within which the actual concentration of the asbestiform fibres in the Thunder Bay water supply may lie.

Bottom Sediments

In 1971, samples (core and dredge) of the bottom sediments were collected by the Ontario Ministry of the Environment in the nearshore zone (zone A in Figure 2), and analysed for heavy metals. The results are in Table 5.

The number of samples is relatively small and it is questionable how well the results represent the whole area. Relatively high concentrations of mercury were found in cell A6 (Figure 2) with concentrations as high as 27 mg/kg. The average concentration of mercury in sediments without the A6 area is 0.106 mg/kg.

Another study of the lake-bottom sediments was carried out by Mothersill in 1974 when samples at 201 stations were collected (15). Sediment samples were analysed for metals and phosphorus and the results are reproduced in Table 6.

There were some general trends in the spatial distribution of concentrations of the various elements. While the determined sediment concentrations of iron, nickel and chromium were irregularly distributed throughout the area, zinc, cobalt, copper, and phosphorus concentrations increased in deeper water zones. Sodium, magnesium and strontium concentrations were highest in the north-central section of the bay. The highest concentrations of calcium were found within the breakwater

TABLE 4

COMPARISON OF THE RESULTS OF ANALYSIS FOR ASBESTOS FIBRES IN WATER

Laboratory	Mean	Range (million fibres/l)
Canada Centre for Inland Waters, Burlington	0.63	0.2 to 1.0
McMaster University, Hamilton	8.45	3.4 to 29
Ontario Research Foundation, Mississauga	0.06	BLD* to 0.16

BLD*-below detection limit of 0.01 million fibres/l

TABLE 5

LAKE-BOTTOM SEDIMENT ANALYSES, THUNDER BAY, NEARSHORE^a

Element	Concentrations in mg/kg					Mn	Ni	Cd
	Hg	Cr	Pb	Zn	As			
Average	2.97	26.5	53.6	95.5	4.4	475	51.3	1.33
Minimum	0.044	7.7	39	55	3.6	320	46	0.96
Maximum	27	46	72	161	5.2	630	60	1.7
Number of Samples	13	12	5	12	2	2	3	2

^aPreviously unpublished MOE data

TABLE 6

LAKE-BOTTOM SEDIMENT ANALYSES, THUNDER BAY^b

Element	Concentrations in mg/kg						Fe
	Ca	K	Na	Mg	Sr		
Minimum	32600	13100	10000	14500	17.3		31500
Maximum	155000	35000	20600	55600	52.8		62300

Element	Mn	Zn	Ni	Cr	Co	Cu	P
Minimum	498	70	50	81	34	27	386
Maximum	7590	723	101	117	60	103	1627

^bModified from Mothersill (15)

and at the northern section near the breakwater while the highest potassium concentrations were within the breakwater and in the eastern part of the study area.

Exchange of Pollutants Between Nearshore and Offshore Waters

A modified method of Palmer (16) was used to estimate the exchange between the nearshore and offshore waters utilizing updated loading data.

The method assumes steady state conditions (constant flows, constant loadings, constant and homogenous concentrations of the cells) and no precipitation in the nearshore zone. These assumptions are never strictly maintained as both concentrations and flows do change with time and certain amounts of water and chemicals are brought in with precipitation. By averaging the results over a long period of time (year) the flow and concentration variations are averaged out. The method and its modification are briefly reviewed below. Similar notation for the flows and concentrations as in (16) is used and is as follows:

Q_D is the sum of volumetric flows from rivers and discharges into the nearshore area ($m^3/year$).

V is the total volume of the nearshore zone (m^3).

$C_D(k_D)$ is the mean concentration of the conservative or non-conservative parameter of the rivers and discharges (mg/l).

$C_L(k_L)$ is the mean concentration of the conservative or non-conservative parameter in the outer lake (mg/l).

$C_{ss}(k_{ss})$ is the mean concentration of the conservative or non-conservative parameter in the nearshore area (mg/l).

The number of flushings per year, F , is defined as $1/\text{residence time}$ and in agreement with equation (4) of Palmer (16) is:

$$F = \frac{1}{t} = \frac{Q_D}{V} \frac{C_D - C_L}{C_{ss} - C_L} \quad (1)$$

Using a simple mathematical rearrangement the following formula for estimation of the percentage of the total loading of non-conservative parameter removed in the nearshore area S , can be derived:

$$S\% = 100 \left[1 + \frac{k_L(C_D - C_{ss}) + k_{ss}(C_L - C_D)}{k_D(C_{ss} - C_L)} \right] \quad (2)$$

It can be seen that the ratio S can be calculated entirely from the known concentrations of both conservative and non-conservative parameters in the loadings, nearshore area and open lake. Both positive and negative values of S are possible.

Results - The calculated values of the residence time, number of flushings per year (defined also as the ratio of the total water passing through the inshore zone and the total volume of this zone), and predicted excess or deficit values for phosphorus and nitrogen are given in Table 3. Results are sensitive to many factors including the loading values and background concentrations in the offshore areas. For this analysis the background concentrations were based on the lowest values found in zone D as well as on information from publications of Schelske and Roth (2), Schelske et al. (10) and Beeton (1). The loadings used for calculation of exchanges for 1973 and 1974 are shown in Table 7. The loadings for 1970 were taken from the 1972 report (4). The calculated flushing times change from 80 days for 1970 to 23 and 21 days for 1973 and 1974 respectively. The results for 1970 are not reliable as the values of loadings are based on limited data. For example, the input flow for 1970 was estimated at one-third of 1973 data. This changes the results by a factor of three. It is believed that the 1973 and 1974 data are more close to reality. There are some interesting results in predicted excess and deficit percentages for phosphorus as the values change from excesses of 65 percent in 1970 to deficit of 19 percent in 1974. The positive values indicate that more phosphorus is being brought into the area than is taken out with the water moving through the zones. This can be explained as a result of excess phosphorus being removed by sedimentation, probably after part of it is first used by phytoplankton and/or by an increase in phosphorus concentration in the area by the end of the period.

The negative 1974 value indicates that less phosphorus was brought into the area than was carried out. This could result either from release of phosphorus from the sediments or from a decrease in the phosphorus concentration in the area by the end of 1974. The later possibility based on this simple model would be supported if the 1975 data show a decline in phosphorus concentrations. For nitrogen, negative values were obtained for 1970 and 1973 data. While no conclusion can be made from rates between 1970 and 1973 as there are no data available for 1971 and 1972, it is observed that the amount of nitrogen in the area in 1974 has declined in comparison with 1973. The positive value for 1974 suggested that more nitrogen was being brought into the area than was carried away and that an increase can be expected in 1975. The values of the residence times are different from that of Palmer (16) (40 day residence time) which may be attributed to different loading and concentration data.

Aquatic Biology

Microbiology, Bacterial Contamination - Total and fecal coliform counts were determined in 1971, 1973 and 1974. The geometric mean total coliform values in the individual zones are given in Table 3 and also shown in Figure 6. The mean values decreased between 1970 and 1974.

TABLE 7

TRIBUTARY, MUNICIPAL AND INDUSTRIAL LOADINGS
THUNDER BAY, ESTIMATE^a

Source	Mean Flow		Mean Concentration, mg/l			Mean Loadings					
	cfs	m ³ x 10 ⁶ /a	Dissolved Solids	Total P	Total N	lb/d			t/a		
						Dissolved Solids	Total P	Total N	Dissolved Solids	Total P	Total N
Kaministiquia R.	2950.0	2634.0	170.0	0.065	0.718	2700000	1040.0	11400	447000	172.00	1890.0
Current R.	269.0	240.0	69.6	0.018	0.562	101000	26.2	815	16700	4.34	135.0
Neebing R.	86.0	76.8	241.0	0.073	0.967	112000	33.9	449	18500	5.61	74.3
McIntyre R.	81.4	72.7	239.0	1.036	6.094	105000	455.0	2680	17400	75.30	443.0
McVicar Bank	20.3	18.1	222.0	0.064	0.702	24300	7.0	77	4020	1.16	12.7
Thunder Bay STP-South	11.1	10.0	345.0	3.08	21.9	20800	186.0	1320	3450	30.80	219.0
Thunder Bay STP-North ^b	12.1	10.8	347.0	3.48	23.0	22600	227.0	1500	3745	37.60	248.0
Abitibi Paper Co.	12.4	11.1	1620.0	0.343	1.840	109000	23.0	123	18000	3.81	20.4
Fort William Divn.											
Great Lakes Paper Co. ^b	71.5	63.9	2500.0	0.355	1.910	967000	137.0	734	160000	22.70	122.0
Dow Chemical Co. ^b	3.9	3.5	136	0.000	0.008	2820	0.0	2	467	0.00	0.3
Industrial Grain Prod. ^b	0.6	0.5	4560	53.0	178.0	13800	160.0	538	2280	26.50	89.1
Canada Malting Co.	1.5	1.3	792	9.80	33.8	6250	77.0	266	1030	12.70	44.0
Northern Wood Pres.	0.01	0.008	250	21.0	25.0	11	1.0	1	2	0.17	0.2
Abitibi Forest Prod.	29.7	26.5	1450	0.256	2.76	233000	41.0	442	38500	6.79	73.2
Provincial Paper Co.											
Abitibi Forest Prod.	21.9	19.6	1430	0.447	2.16	170000	53.0	256	28100	8.77	42.4
Thunder Bay Divn.											
Sum of loadings or mean concentration	3480	3111	191	0.112	0.977	3590000	2100	18400	595000	348	3040

^a Averages, based on 1973, 1974 and 1975 data.

^b Not included in the sum as they are already included in the tributary streams.

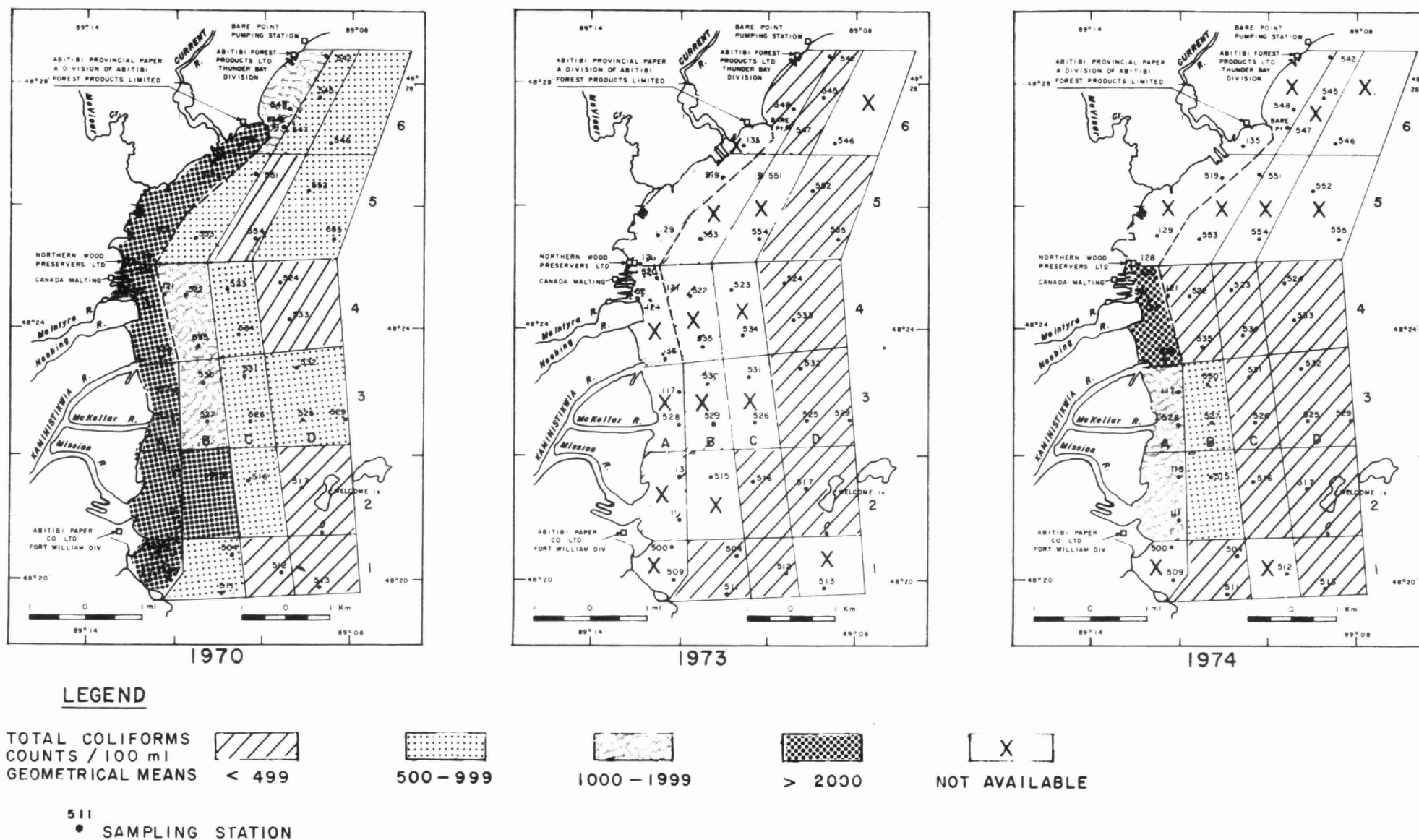


FIGURE 6 : CHANGE IN TOTAL COLIFORMS IN THUNDER BAY 1970 - 1974

No data are available for the northern part of the area in 1974. There is an apparent improvement in the total coliforms over the survey years. The Ontario provincial criteria (12) for body contact recreation (1000 coliforms/100 ml) were exceeded in zone A in 1970 and 1974 while in zone B only 1970 data are over the limit. Surface water permissible criteria (5000 coliforms/100 ml) were not exceeded in any zone.

Fish - A fish sampling program was designed to determine baseline levels of selected contaminants in the sport and commercially valuable fish species collected in Thunder Bay. Fifty mature fish (one year plus) of a similar common size of each of three designated species were collected during 1973 and 1974 and analyzed for PCB's, pesticides, metals and radioactivity.

A sample for analysis consisted of a homogenized composite of the flesh of five fish of the same species. All results were calculated on a wet basis per gram sample. The results are shown in Table 8.

Results PCB and Pesticides - Presently there are no Canadian regulations governing levels of pesticides in edible portions of fresh water fish. The Great Lakes Water Quality Board has recommended that the concentrations of total PCB's in fish (whole fish on a wet weight basis) should not exceed 0.1 mg/kg for the protection of fish-consuming birds and animals (17). As the recommended value is for whole fish samples while most of the analyses were done for flesh samples, comparison of the two sampling methods was carried out for slimy sculpins collected in Thunder Bay in July 1975. PCB and pesticide analysis of whole fish showed reduced levels of organic compounds when compared to the results derived from flesh samples.

Results of the analysis for organochlorine compounds indicated low levels of contamination. Higher levels of DDT and its metabolites consistently occurred in lake trout specimens. A mean concentration of 865 µg/kg was found in lake trout samples. This maximum value of the sum of DDT and its metabolites is less than the 1.0 mg/kg level recommended for whole fish in the Water Quality Objectives Subcommittee Report (17). The level of dieldrin did not in any case exceed the 0.3 µg/kg level recommended for edible portions of the fish (17).

Heavy Metals - Table 8 also presents the data for heavy metal concentrations along with allowable limits, where applicable. Mercury was the only metal found to approach or exceed the present guideline level of 0.5 mg/kg as recommended in the Food and Drug Act and Regulations (18). In the three species tested, the mean concentration of mercury was above the recommended level only for lake trout with a value of 0.7 mg/kg. The Canadian Federal Food and Drug Directorate (18) has set the following acceptable heavy metal levels for fresh water animal products: arsenic - 5 mg/kg, lead - 10 mg/kg, copper - 100 mg/kg, zinc - 100 mg/kg, nickel - 5 mg/kg and cadmium - 0.5 mg/kg. None of the samples analyzed had heavy metal concentrations greater than 10 percent of these

TABLE 8

THUNDER BAY FISH ANALYSES

Contaminant, Element or Radioactivity	Whitefish ^a		Lake Trout ^a		Lake Herring ^a		Suggested Limit (reference) mg/kg
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Dieldrin	0.025	0.012	0.044	0.012	0.020	0.003	0.3 (17)
PCB	0.80	0.18	1.72	0.32	0.71	0.20	0.1 (17)
pp'DDE	0.24	0.082	0.51	0.095	0.28	0.059	-
pp'DDD	0.034	0.008	0.046	0.012	0.031	0.007	-
pp'DDT	0.162	0.042	0.10	0.047	0.17	0.053	-
op'DDT	0.068	0.014	0.10	0.022	0.064	0.014	-
ΣDDT + Metabolites	0.50	-	0.86	-	0.55	-	-
Cu	0.51	0.38	0.49	0.26	0.49	0.13	100.0 (18)
Ni	0.22	0.32	<0.02-0.25	-	<0.02	-	5.0 (18)
Pb	1.21	1.60	<0.2 -4.98	-	<0.02	-	10.0 (18)
Zn	4.09	0.62	3.39	0.67	6.21	1.92	100.0 (18)
Cd	0.08	0.03	0.28	0.44	0.06	0.02	0.5 (18)
Mn	0.15	0.07	0.15	0.12	0.20	0.06	-
As	<0.01-0.11	-	<0.01-0.30	-	0.13	0.03	5.0 (18)
Cr	1.01	0.58	0.60	0.56	0.18	0.09	-
Se	0.11	0.04	0.15	0.08	0.16	0.03	-
Hg	0.12	0.03	0.70	0.06	0.17	0.02	0.5 (18)
Gross α pCi/g	<1.0	-	<1.0	-	<1.0	-	-
Gross β pCi/g	2.59	0.63	1.88	1.38	3.80	0.36	-

^aAll results in mg/kg wet weight unless shown otherwise;

Means calculated from 10 samples, each consisting of a composite of flesh from five fish.

accepted levels with the exception of 10 composite whitefish samples with a mean lead content of 1.21 mg/kg.

Radioactivity in Fish - Presently there are no maximum levels established for radioactivity other than the recommendation that radioactivity be kept at the lowest practicable level to prevent harmful effect on health.

All samples analyzed had a gross α level of less than 1.0 pCi/g based on the wet weight of sample (Table 8). Samples analyzed for gross β radioactivity had a range of mean values from a maximum of 3.80 in herring samples to a minimum of 1.88 pCi/g in lake trout samples.

Summary - Lake trout samples consistently had higher levels of PCB's and pesticide residues than whitefish or lake herring. A predator species such as lake trout tends to further accumulate the body burden carried by other species. No relationship could be developed between the mean extractible oil content of fish and levels of PCB's and DDT.

Heavy metal contamination of fish was minimal with the exception of mercury. Lake trout samples had mercury levels exceeding the recommended safe concentration for human consumption. Results from the survey indicate that there had been little change from recent historical information with respect to other heavy metal concentrations.

There was little variation in radioactivity levels from species to species. As there are no current numerical criteria for radioactivity levels in fish, the data presented are difficult to interpret but do provide base-line levels for comparison with future surveys.

SUMMARY OF EXISTING AND DEVELOPING PROBLEMS

The nearshore waters in Thunder Bay are being impaired by local, industrial and municipal waste water discharges. Even though this report is limited to the years 1970 to 1974, which is a relatively short period of time, some of the parameters are showing distinctive changes. Very limited data are available on dissolved oxygen for 1973, however, indications are that the dissolved oxygen is still quite high in the area. The amount of nutrients has changed since 1970. While nitrogen was slightly lower in 1974 than in 1970, total phosphorus has increased significantly. There are not enough data on phytoplankton production to make any conclusions on phytoplankton production in relation to nutrient levels. Dissolved solids have remained nearly constant while the total coliform count has declined. Water movements in the area are predominantly from north to south with the currents generally slower for the north part of the bay. This is important for determination of the fate of pollutants in the region as the clean lake water enters the bay from north and bay water leaves the bay at south.

Thunder Bay is a rapidly growing community. Both the industrial development and population are expected to increase in the near future. At present, expansion programs are underway on the Ontario Hydro Thermal Generating Station and Great Lakes Paper Company, a new coal handling terminal is being constructed and other smaller developments are progressing. The importance of Thunder Bay as a port is increasing, with expected rises in the amounts of grain, lumber, ore, chemicals and other commodities shipped. All these expansions will result in population growth and will have direct or indirect impact on water use and pollution problems in the area.

The municipal water supply with a total capacity of 105,000 m³/d (23 MIGD) is expected to be able to meet the projected demands for the next 20 years. The expansion of the municipal primary sewage treatment plant capacity from 27,000 m³/d (6 MIGD) to 110,000 m³/d (24 MIGD) will, when finished in 1977, provide adequate capacity to handle the municipal sewage. This construction program will essentially remove all untreated sewage discharges to watercourses in and around Thunder Bay. No nutrient removal program is planned at this time. The need for nutrient removal should be reassessed, as the documented rapid increase of phosphorus concentrations in the area could lead to a serious degradation of the nearshore waters. Of the total phosphorus loadings into the bay, the municipal and industrial sources account for about 43 percent. Of this, 23 percent are industrial while 20 percent are municipal discharges. Municipal and industrial sources of total nitrogen account for only 28 percent of the total with 13 percent from industrial and 15 percent from municipal discharges. The percentage of the uncontrollable sources of nutrients is quite high and nutrient removal at treatment plants could only eliminate part of the total load.

There is a small amount of asbestos fibres in the municipal water supply in Thunder Bay. No conclusion on the possible health effects can be made at the present time, as neither the analytical methods are reliable nor is a satisfactory standard for asbestos fibres in drinking water available.

Mercury is still a problem in Thunder Bay. Lake trout samples from 1973 and 1974 have a mean mercury content above the recommended safe concentration for human consumption while the samples of whitefish and herring had concentrations below the safe level. The situation should be improving since the closure of the Dow Chemical company's chlor-alkali plant on the Kaministiquia River in 1973. Material dredged from the river is tested for mercury content and only uncontaminated material is disposed in the lake.

Several additional remedial measures are being carried out by the local industries, including sulphite mill expansion and conversion directed towards load reduction and complete recycling at the kraft mill operated by the Great Lakes Paper Company Ltd.

Bacterial contamination is not serious except in the Inner Harbour where the standards for body contact recreation are periodically exceeded.

Due to its population and industrialization, Thunder Bay is one of the "areas of concern" on Lake Superior. Because the historical data are scarce and incomplete, the trends in water quality can not be established with confidence yet. Baseline data are now available to aid in detecting future changes.

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APPENDIX TABLE 1

Water Quality Data 1973 Thunder Bay

Water Quality Data 1979 (Thunder Bay)																									
Conductivity umhos/cm				Ammonia N-mg/l		Total Kjeldahl N-mg/l			Nitrite N-mg/l			Nitrate N-mg/l			Total Nitrogen N-mg/l			Total Phosphorus mg/l			Dissolved Phosphorus mg/l				
Stn.	Zone	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.
113	A	114.8	4.75	6	0.020	0.000	2	0.315	0.064	2	0.0040	0.0014	2	0.125	0.078	2	0.444	0.016	2	0.0255	0.0163	2	0.0060	0.0014	2
121	B	102.5	2.12	2	0.025	0.007	2	0.245	0.021	2	0.0030	0.0014	2	0.150	0.071	2	0.398	0.093	2	0.0195	0.0148	2	0.0040	0.0014	2
124	A	114.1	5.27	7	0.043	0.024	9	0.276	0.062	9	0.0044	0.0009	9	0.125	0.018	9	0.405	0.050	9	0.0314	0.0071	9	0.0090	0.0061	9
131	A	106.2	2.12	2	0.015	0.007	2	0.290	0.099	2	0.0035	0.0007	2	0.125	0.064	2	0.418	0.163	2	0.0345	0.0064	2	0.0040	0.0014	2
135	A	126.1	12.49	18	0.020	0.010	3	0.480	0.063	4	0.0037	0.0006	3	0.041	0.051	3	0.545	0.032	3	0.0398	0.0101	4	0.0067	0.0040	3
511	B	101.0	1.41	2	0.020	0.010	2	0.200	0.057	2	0.0030	0.0014	2	0.150	0.071	2	0.353	0.129	2	0.0095	0.0007	2	0.0102	0.0086	4
512	C	100.0	0.00	2	0.020	0.000	2	0.210	0.156	2	0.0030	-	2	0.145	0.092	2	0.358	0.064	2	0.0125	0.0092	2	0.0040	0.0014	2
514	B	103.5	0.71	2	0.020	0.014	2	0.535	0.431	2	0.0035	0.0007	2	0.115	0.106	2	0.654	0.325	2	0.0155	0.0078	2	0.0035	0.0007	2
515	B	106.5	2.35	6	0.015	0.006	4	0.232	0.079	4	0.0028	0.0015	4	0.140	0.057	2	0.375	0.093	4	0.0130	0.0064	4	0.0035	0.0010	4
516	C	99.8	1.33	6	0.010	0.000	2	0.265	0.007	2	0.0030	0.0014	2	0.145	0.078	2	0.413	0.072	2	0.0125	0.0049	2	0.0035	0.0007	2
517	D	99.8	0.84	5	0.015	0.071	2	0.225	0.035	2	0.0035	0.0021	2	0.150	0.085	2	0.378	0.052	2	0.0115	0.0007	2	0.0045	0.0007	2
519	A	108.9	4.37	16	0.010	0.000	2	0.420	0.056	2	0.0055	0.0007	2	0.056	0.008	2	0.481	0.048	2	0.0470	0.0240	2	0.0050	0.000	2
520	A	109.5	0.71	2	0.050	0.042	2	0.370	0.140	2	0.0045	0.0007	2	0.130	0.085	2	0.504	0.057	2	0.0485	0.0304	2	0.0255	0.0159	4
521	A	124.9	17.49	16	0.030	0.028	2	0.465	0.049	2	0.0055	0.0020	2	0.134	0.093	2	0.604	0.141	2	0.0890	0.0127	2	0.0070	0.0057	2
522	B	102.5	3.54	2	0.0175	0.005	4	0.198	0.036	2	0.0028	0.0010	4	0.162	0.085	4	0.355	0.080	4	0.0198	0.0114	4	0.00425	0.0005	4
523	C	99.5	0.71	2	0.015	0.007	2	0.265	0.092	2	0.0025	0.0007	2	0.150	0.085	2	0.418	0.006	2	0.0125	0.0049	2	0.0035	0.0007	2
524	D	99.5	0.71	2	0.015	0.007	2	0.200	0.014	2	0.0020	-	2	0.160	0.085	2	0.362	0.098	2	0.0095	0.0021	2	0.0030	0.000	2
527	B	107.2	9.25	8	0.019	0.009	10	0.171	0.083	10	0.0032	0.0010	10	0.144	0.030	10	0.318	0.066	10	0.0137	0.0090	10	0.0037	0.0020	10
533	D	97.8	0.41	6	0.015	0.007	2	0.210	0.014	2	0.0025	0.0007	2	0.155	0.092	2	0.368	0.077	2	0.0160	0.0130	2	0.0050	0.0020	10
534	C	98.2	0.41	6	0.020	0.014	2	0.260	0.014	2	0.0035	0.0007	2	0.145	0.064	2	0.408	0.078	2	0.0115	0.0035	2	0.0030	-	1
535	B	108.2	6.94	6	0.015	0.006	4	0.268	0.119	4	0.0035	0.0017	4	0.158	0.083	4	0.428	0.114	4	0.0475	0.0689	4	0.0032	0.0013	4
536	A	114.2	9.75	6	0.035	0.007	2	0.375	0.134	2	0.005	0.0014	2	0.125	0.064	2	0.505	0.199	2	0.041	0.0141	2	0.0075	0.0035	2
542	B	97.8	0.97	17	0.017	0.006	3	0.197	0.055	3	0.0020	0.0000	3	0.141	0.086	3	0.340	0.081	3	0.011	0.0035	3	0.0060	0.0030	3
545	C	99.5	0.71	2	0.020	0.000	2	0.195	0.021	2	0.0025	0.0007	2	0.170	0.099	2	0.368	0.121	2	0.017	0.0057	2	0.0045	0.0021	2
546	D	99.7	1.37	6	0.150	0.007	2	0.190	0.113	2	0.0020	-	2	0.165	0.092	2	0.357	0.205	2	0.012	0.0071	2	0.0065	0.0035	2
547	B	99.3	0.82	6	0.150	0.007	2	0.185	0.007	2	0.0020	-	2	0.180	0.113	2	0.367	0.120	2	0.008	0.000	2	0.005	0.0014	2
553	B	98.6	1.27	14	0.020	-	1	0.175	0.092	2	0.0050	0.0014	2	0.082	0.003	2	0.262	0.093	2	0.016	0.0106	2	0.0035	0.0021	2

APPENDIX TABLE 1

Water Quality Data 1973 Thunder Bay (continuation)

Stn. Zone	Chloride mg/l			Sulphate mg/l			Dissolved Oxygen mg/l			Total Coliforms per 100 ml			Fecal Coliforms per 100 ml		Enterococci per 100 ml		Chlorophyll a µg/l			Secchi Disc m		
	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Geom. Mean	St. Dev.	No.	Geom. Mean	No.	Geom. Mean	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.
113 A	5.29	0.49	7	-	-	-	9.00	-	1	475*	-	6	9.5	7	22.1	7	1.42	0.532	4	1.02	0.608	4
121 B	4.00	1.00	3	-	-	-	8.40	-	1	361*	-	6	9.3	8	29.4*	7	1.35	0.493	4	2.00	1.410	4
124 A	2.78	1.30	9	-	-	-	8.84	0.63	9	720*	-	1	46.8*	7	270.1*	6	2.28	0.718	4	1.18	0.259	5
131 A	4.33	0.58	3	-	-	-	7.60	-	1	479*	-	5	19.9	8	36.4*	7	1.98	0.896	4	1.18	0.222	4
135 A	5.00	1.87	5	-	-	-	5.20	1.41	17	406*	-	8	9.9	9	6.3*	10	1.22	0.436	6	0.75	0.274	6
511 B	3.67	0.58	3	2.5	0.71	2	12.00	-	1	105	-	7	1.2	7	2.0	7	1.04	0.297	5	2.90	0.418	5
512 C	3.33	0.58	3	-	-	-	9.60	-	1	40	-	8	1.2	8	1.0	8	1.18	0.427	4	3.50	0.707	4
514 B	4.33	1.52	3	-	-	-	8.40	-	1	308*	-	5	8.6	7	3.0	7	1.37	0.657	3	1.75	0.289	4
515 B	3.88	0.64	8	-	-	-	9.20	1.13	2	-	-	-	-	-	-	-	1.35	0.719	4	1.88	1.548	4
516 C	3.00	0.58	7	-	-	-	10.00	-	1	83	-	8	2.4	8	1.7	8	1.08	0.655	4	4.00	1.155	4
517 D	3.43	0.79	7	-	-	-	10.40	-	1	54	-	8	1.0	8	1.4	8	1.15	0.723	4	4.50	0.707	4
519 A	3.50	2.12	2	-	-	-	7.70	0.79	16	155	-	2	31.0	2	2.8	2	1.70	0.707	2	1.15	0.495	2
520 A	4.67	1.15	3	3.00	0.00	2	8.20	-	1	624	-	7	17.1	8	24.1*	5	1.40	0.548	4	0.92	0.299	4
521 A	1.00	0.00	2	-	-	-	7.23	1.40	16	942	-	2	44.2	2	166.9	2	1.65	0.919	2	1.00	0.000	2
522 B	3.50	0.58	4	-	-	-	9.60	1.41	2	62*	-	7	2.1	8	2.3	8	1.20	0.762	4	3.50	0.816	4
523 C	3.00	1.00	3	-	-	-	10.00	-	1	-	-	-	-	-	-	-	0.92	0.556	4	4.00	0.707	4
524 D	3.33	0.58	3	-	-	-	10.00	-	1	41	-	8	1.5	8	1.6	8	0.92	0.538	4	4.62	0.750	4
525 D	-	-	-	-	-	-	-	-	-	31	-	8	1.2	8	1.0	8	-	-	-	-	-	-
527 B	2.20	1.23	10	-	-	-	9.94	1.40	10	192*	-	16	6.0	18	4.1	18	1.60	0.903	5	4.00	1.696	5
533 D	3.00	0.58	7	-	-	-	11.40	-	1	44	-	9	1.4	9	1.5	9	1.18	0.785	4	3.62	1.250	4
534 C	3.29	0.49	7	-	-	-	9.20	-	1	-	-	-	-	-	-	-	1.18	0.763	4	4.00	1.225	4
535 B	4.12	0.99	8	-	-	-	9.30	2.69	2	137	-	8	3.5	8	7.3	8	1.68	0.866	4	2.08	1.374	4
536 A	5.00	0.58	7	-	-	-	8.00	-	1	297*	-	5	11.0	8	49.2	8	1.35	0.545	4	1.12	0.254	4
541 B	-	-	-	-	-	-	-	-	-	41	-	7	1.0	8	3.0	8	-	-	-	-	-	-
542 B	3	2.12	5	-	-	-	10.08	0.600	17	73	-	2	2.4	1	1.0	2	1.18	0.331	6	4.58	1.038	6
545 C	3.33	0.58	3	-	-	-	11.40	-	1	15	-	8	1.3	8	2.0	8	1.02	0.359	4	4.28	1.403	4
546 D	3.29	0.49	7	-	-	-	10.60	-	1	-	-	-	-	-	-	-	1.00	0.455	4	4.28	1.723	4
547 B	3.14	0.38	7	-	-	-	11.40	-	1	61	-	7	2.1	8	4.4	8	1.00	0.432	4	3.75	1.708	4
552 D	-	-	-	-	-	-	-	-	-	35	-	8	2.0	8	2.9	8	-	-	-	-	-	-
553 B	1.00	0.00	2	-	-	-	10.02	0.43	16	193*	-	9	3.8	10	4.5	10	1.60	0.707	2	3.00	0.000	2

* Some samples analysed with a result "too numerous to count";
mean calculated without this point(s).

APPENDIX TABLE 2
WATER QUALITY DATA 1974, THUNDER BAY

Station	Zone	Conductivity umhos/cm			Ammonia N-mg/l			Total Kjeldahl N-mg/l			Nitrite N-mg/l			Nitrate N-mg/l			Total Nitrogen N-mg/l			Total Phosphorus mg/l			Dissolved Phosphorus mg/l		
		Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.	Mean	St. Dev.	No.
111	A	105	8.42	4	0.03	0.012	4	0.2	0.12	2	0.004	0.001	4	0.005	0.004	4	0.295	0.12	2	0.074	0.080	2	0.007	0.004	4
113	A	102	7.6	3	0.03	0.006	3	0.28	0.04	2	0.004	0.001	3	0.010	0.006	3	0.291	0.04	2	0.111	0.126	2	0.069	0.105	3
117	A	104	1.3	4	0.03	0.024	4	0.25	0.08	4	0.003	0.002	4	0.009	0.006	4	0.266	0.073	4	0.017	0.005	4	0.006	0.005	4
121	B	105	4.0	6	0.05	0.04	5	0.32	0.09	4	0.003	0.001	5	0.008	0.003	5	0.337	0.087	4	0.066	0.049	4	0.016	0.017	5
124	A	108	1.6	5	0.029	0.027	5	0.34	0.064	5	0.004	0.001	5	0.012	0.006	5	0.357	0.06	5	0.050	0.045	5	0.029	0.051	5
128	A	107	3.4	5	0.011	0.005	5	0.29	0.024	5	0.004	0.001	5	0.008	0.004	5	0.304	0.023	5	0.027	0.003	4	0.004	0.001	5
129	A	105	1.58	5	0.027	0.033	5	0.24	0.038	5	0.004	0.001	5	0.006	0.003	5	0.252	0.039	5	0.042	0.05	5	0.023	0.031	5
131	A	102	0.71	5	0.018	0.019	3	0.25	0.012	3	0.003	0.001	3	0.009	0.006	3	0.258	0.016	3	0.025	0.022	3	0.009	0.012	3
135	A	108	6.5	5	0.019	0.015	5	0.30	0.095	4	0.004	0.002	5	0.004	0.005	5	0.310	0.095	4	0.028	0.029	4	0.014	0.018	5
500	A	109	7.49	7	0.019	0.01	6	0.26	0.07	6	0.003	0.001	6	0.013	0.005	6	0.277	0.069	6	0.025	0.022	6	0.005	0.002	6
504	B	102	5.2	4	0.030	0.01	3	0.21	0.05	2	0.003	0.002	3	0.009	0.002	3	0.228	0.048	2	0.008	-	1	0.005	0.001	2
509	A	99	10.6	7	0.068	0.073	6	0.32	0.09	6	0.007	0.007	6	0.012	0.006	6	0.337	0.09	6	0.065	0.044	4	0.029	0.028	6
511	B	102	2.36	7	0.024	0.012	7	0.23	0.067	5	0.003	0.002	7	0.015	0.005	7	0.064	0.246	5	0.018	0.015	5	0.007	0.007	7
513	D	99	1.22	5	0.026	0.005	5	0.17	0.054	5	0.003	0.002	5	0.010	0.002	5	0.186	0.056	5	0.044	0.051	5	0.023	0.026	5
515	B	104	5.00	4	0.020	0.01	3	0.29	0.099	3	0.003	0.002	3	0.006	0.004	3	0.296	0.097	3	0.027	0.018	3	0.007	0.003	3
516	C	100	3.32	4	0.027	0.015	3	0.24	0.025	3	0.003	0.003	3	0.008	0.004	3	0.247	0.023	3	0.014	0.007	3	0.010	0.007	3
517	D	98	1.5	4	0.023	0.006	3	0.18	0.021	3	0.002	0.001	3	0.010	0.002	3	0.188	0.021	3	0.006	0.002	3	0.003	0.002	3
519	A	103	4.67	5	0.019	0.013	4	0.3	0.057	4	0.004	0.002	4	0.007	0.003	4	0.308	0.06	4	0.062	0.056	4	0.020	0.031	4
520	A	110	5.31	5	0.021	0.18	5	0.37	0.068	5	0.004	0.001	5	0.008	0.004	5	0.380	0.067	5	0.067	0.019	5	0.017	0.017	5
521	A	113	5.18	5	0.048	0.028	5	0.43	0.168	5	0.004	0.002	5	0.007	0.004	5	0.445	0.168	5	0.066	0.054	5	0.014	0.016	5
522	B	100	1.21	6	0.018	0.01	6	0.33	0.04	2	0.002	0.001	6	0.011	0.004	6	0.347	0.035	2	0.016	-	1	0.004	0.003	5
523	C	99	0.52	6	0.023	0.015	6	0.24	0.10	5	0.001	0.001	6	0.012	0.005	6	0.249	0.010	5	0.041	0.052	5	0.019	0.028	6
524	D	99	0.52	6	0.018	0.012	6	0.20	0.042	4	0.002	0.001	6	0.013	0.005	6	0.211	0.038	4	0.008	0.007	4	0.005	0.005	6
525	D	99	0.00	2	0.01	0.000	2	0.14	-	1	0.001	0.000	2	0.015	0.008	2	0.161	0	1	0.009	-	1	0.002	0.000	2
526	C	99	1.29	4	0.02	0.008	4	0.20	0.049	3	0.003	0.001	4	0.012	0.005	4	0.213	0.052	3	0.015	0.006	3	0.004	0.002	4
527	B	100	2.4	4	0.023	0.03	4	0.19	0.021	4	0.003	0.001	4	0.014	0.004	4	0.204	0.021	4	0.013	0.007	3	0.008	0.008	3
528	A	105	5.9	4	0.053	0.032	4	0.27	0.095	3	0.004	0.001	4	0.007	0.002	4	0.282	0.093	3	0.026	0.015	3	0.009	0.002	4
529	D	99	1.58	5	0.018	0.01	4	0.20	0.053	3	0.002	0.001	4	0.013	0.005	4	0.184	0.015	2	0.063	0.049	3	0.014	0.021	4
530	B	100	1.5	4	0.018	0.015	4	0.22	0.04	4	0.002	0.001	4	0.008	0.001	4	0.227	0.041	4	0.020	0.026	4	0.013	0.021	4
531	C	99	1.5	4	0.023	0.005	4	0.19	0.025	4	0.002	0.001	4	0.015	0.005	4	0.204	0.026	4	0.023	0.020	4	0.013	0.019	4
532	D	99	0.0	2	0.01	0.000	2	0.15	0.04	2	0.001	0.000	2	0.009	0.000	2	0.160	0.040	2	0.006	0.004	2	0.002	0.000	2
533	D	99	0.957	4	0.02	0.01	3	0.18	0.042	3	0.003	0.001	3	0.009	0.002	3	0.195	0.043	3	0.059	0.044	3	0.031	0.027	3
534	C	99	0.5	4	0.027	0.006	3	0.21	0.05	3	0.003	0.001	3	0.010	0.002	3	0.219	0.053	3	0.045	0.044	3	0.024	0.018	3
535	B	101	2.2	4	0.023	0.010	4	0.19	0.07	4	0.003	0.002	4	0.015	0.007	4	0.205	0.066	4	0.009	0.005	3	0.004	0.002	3
536	A	109	5.7	4	0.060	0.030	3	0.41	0.13	4	0.004	0.001	3	0.005	0.001	3	0.475	0.074	3	0.035	0.017	4	0.006	0.002	3
542	B	99	0.71	2	0.035	0.035	2	0.43	0.057	2	0.003	0.000	2	0.008	0.002	2	0.441	0.059	2	0.044	-	1	0.009	0.001	3
545	C	99	0.50	4	0.013	0.006	3	0.16	0.015	3	0.002	0.001	3	0.012	0.005	3	0.177	0.012	3	0.005	0.003	3	0.005	0.003	3
546	D	99	0.00	2	0.020	0.014	2	0.18	0.08	2	0.003	0.001	2	0.010	0.002	2	0.197	0.076	2	0.063	0.076	2	0.010	0.007	2
547	B	99	0.00	3	0.015	0.007	2	0.26	0.13	2	0.003	0.001	2	0.008	0.001	2	0.271	0.127	2	0.048	0.047	2	0.040	0.040	2
548	B	100	0.71	2	0.020	0.000	2	0.18	0.049	2	0.001	0.000	2	0.017	0.000	2	0.203	0.049	2	0.009	0.004	2	0.003	0.001	2
551	B	101	2.17	5	0.030	0.019	5	0.28	0.131	4	0.002	0.001	5	0.011	0.006	5	0.294	0.127	4	0.058	0.088	3	0.045	0.055	4
552	D	99	0.71	2	0.020	0.000	2	0.15	0.007	2	0.001	0.000	2	0.019	0.000	2	0.175	0.007	2	0.004	0.001	2	0.002	0.000	2
553	B	99	0.35	8	0.033	0.039	4	0.30	0.099	3	0.002	0.002	4	0.011	0.003	4	0.311	0.098	3	0.064	0.083	3	0.018	0.024	4
554	C	100	1.75	6	0.026	0.013	5	0.20	0.115	5	0.002	0.002	5	0.014	0.006	4	0.164	0.043	4	0.013	0.011	4	0.006	0.006	4
555	D	99	0.52	6	0.036	0.032	5	0.17	0.05	5	0.002	0.001	5	0.015	0.005	5	0.191	0.046	5	0.028	0.046	5	0.006	0.005	5

APPENDIX TABLE 2 (Continuation)
WATER QUALITY DATA 1974, THUNDER BAY

Station	Zone	Chloride mg/l			Total Coliforms per 100 ml			Fecal Coliforms per 100 ml			Enterococci Per 100 ml			Chlorophyll <u>a</u> µg/l			Secchi Disc m		
		Mean	St. Dev.	No.	Geom. Mean	St. Dev.	No.	Geom. Mean	St. Dev.	No.	Geom. Mean	St. Dev.	No.	Geom. Mean	St. Dev.	No.	Geom. Mean	St. Dev.	No.
111	A	3.6	1.76	4	1220	-	6	86.2	-	6	40.0	-	6	1.0	-	1	1.8	-	1
113	A	2.3	0.6	3	1247	-	6	96.2	-	6	37.9	-	6	1.0	-	1	1.8	-	1
117	A	2.3	0.5	4	1642	-	6	159.4	-	6	142.7	-	6	-	-	-	1.5	-	1
121	B	2.5	0.81	6	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-	1
124	A	2.3	0.19	4	-	-	-	-	-	-	-	-	-	-	-	-	1.6	-	1
128	A	2.3	0.3	4	-	-	-	-	-	-	-	-	-	-	-	-	1.5	-	1
129	A	2.1	0.17	4	-	-	-	-	-	-	-	-	-	-	-	-	1.8	-	1
131	A	1.8	0.21	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
135	A	3.1	0.85	4	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-	1
500	A	2.7	0.97	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
504	B	2.1	0.41	4	145	-	6	4.7	-	6	3.2	-	6	-	-	-	-	-	-
509	A	2.4	0.62	6	-	-	-	-	-	-	-	-	-	1.0	-	1	1.8	-	1
511	B	1.8	0.31	6	-	-	-	-	-	-	-	-	-	1.0	-	1	2.5	-	1
513	D	1.8	0.18	5	21	-	6	1.6	-	6	1.3	-	6	-	-	-	-	-	-
515	B	2.5	0.9	4	553	-	6	64.7	-	6	10.3	-	6	1.0	-	1	1.2	-	1
516	C	2.1	0.64	4	143	-	6	3.6	-	6	2.4	-	6	1.0	-	1	2.0	-	1
517	D	1.8	0.17	4	42.6	-	6	1.6	-	6	1.0	-	6	-	-	-	2.6	-	1
519	A	2.3	0.42	4	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-	1
520	A	2.5	0.48	4	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-	1
521	A	2.7	0.51	4	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-	1
522	B	1.6	0.18	6	-	-	-	-	-	-	-	-	-	-	-	-	3.0	-	1
523	C	1.5	0.008	6	-	-	-	-	-	-	-	-	-	-	-	-	3.6	-	1
524	D	1.5	0.150	6	-	-	-	-	-	-	-	-	-	-	-	-	5.0	-	1
525	D	1.7	0.220	4	19	-	6	2.0	-	6	1.8	-	6	-	-	-	3.0	-	1
526	C	1.7	0.060	4	128	-	6	3.8	-	6	4.6	-	6	-	-	-	3.0	-	1
527	B	1.7	0.170	4	551	-	6	42.5	-	6	11.4	-	6	-	-	-	-	-	1
528	A	2.3	0.59	4	1516	-	6	162.3	-	6	54.5	-	6	-	-	-	2.0	-	1
529	D	1.7	0.19	5	19.4	-	6	2.3	-	6	1.6	-	6	-	-	-	3.0	-	1
530	B	1.8	0.05	4	768	-	6	58.4	-	5	17.1	-	6	-	-	-	1.6	-	1
531	C	1.5	0.096	4	90	-	6	6.4	-	6	2.5	-	6	-	-	-	4.5	-	1
532	D	1.6	0.071	2	56.2	-	6	3.7	-	6	1.6	-	6	-	-	-	-	-	-
533	D	1.5	0.096	4	44.2	-	6	1.3	-	6	1.3	-	6	-	-	-	4.5	-	1
534	C	1.6	0.096	4	71.2	-	6	2.8	-	6	2.8	-	6	-	-	-	4.5	-	1
535	B	1.8	0.36	4	396	-	6	12.1	-	6	7.1	-	6	-	-	-	1.5	-	1
536	A	3.0	1.10	4	2107	-	6	143.3	-	6	139.1*	-	5	-	-	-	1.1	-	1
542	B	1.6	0.00	2	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	1
545	C	1.6	0.180	4	-	-	-	-	-	-	-	-	-	-	-	-	5.0	-	1
546	D	1.5	0.07	2	-	-	-	-	-	-	-	-	-	-	-	-	6.0	-	1
547	B	1.6	0.208	3	-	-	-	-	-	-	-	-	-	-	-	-	2.1	-	1
548	B	1.8	0.000	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
551	B	1.6	0.15	5	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	1
552	D	1.7	0.00	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
553	B	1.5	0.136	8	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	1
554	C	1.6	0.05	6	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	1
555	D	1.6	0.11	5	-	-	-	-	-	-	-	-	-	-	-	-	5.5	-	1

* Some samples analyzed with a result "too numerous to count";
mean calculated without this point(s).